The University of Texas

Railplug Ignition System for Enhancing Engine Performance and Reducing Maintenance

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COOPERATIVE AGREEMENT DE-FC26-01NT41334

Awarded 9/30/01, 36 Month Duration

$670,481 Total Contract Value ($491,460 DOE)

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Project Objectives

Overall objective: improved ignition system and igniter for large bore natural gas engines

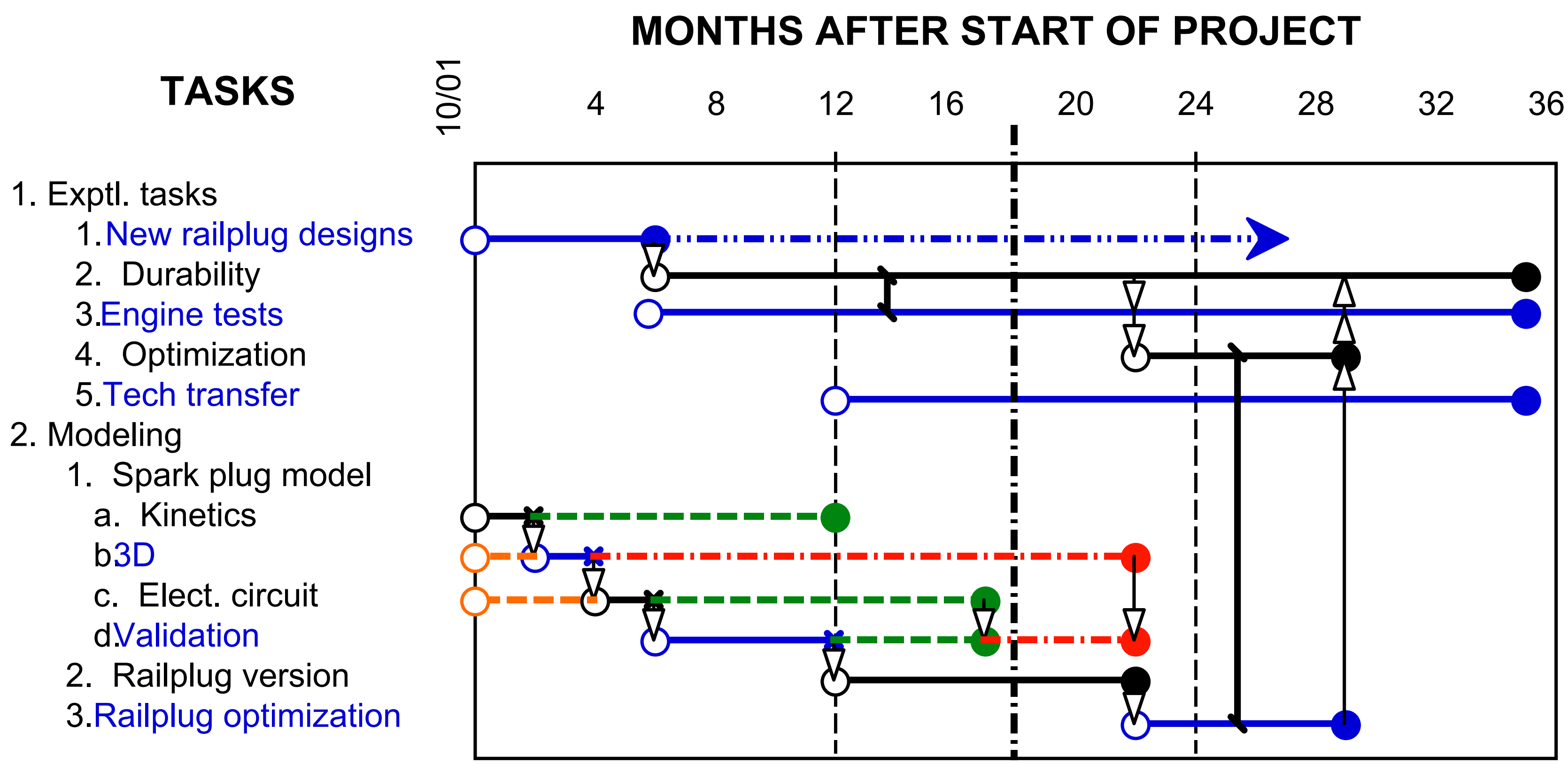
MODELING

- Develop an improved model of the spark ignition process for conventional spark plugs
  - Physics
  - Kinetics
  - Circuit effects
- Extend model to railplugs

EXPERIMENTS

- Develop railplugs suitable for LBNGEs

Project Schedule



Accomplishments

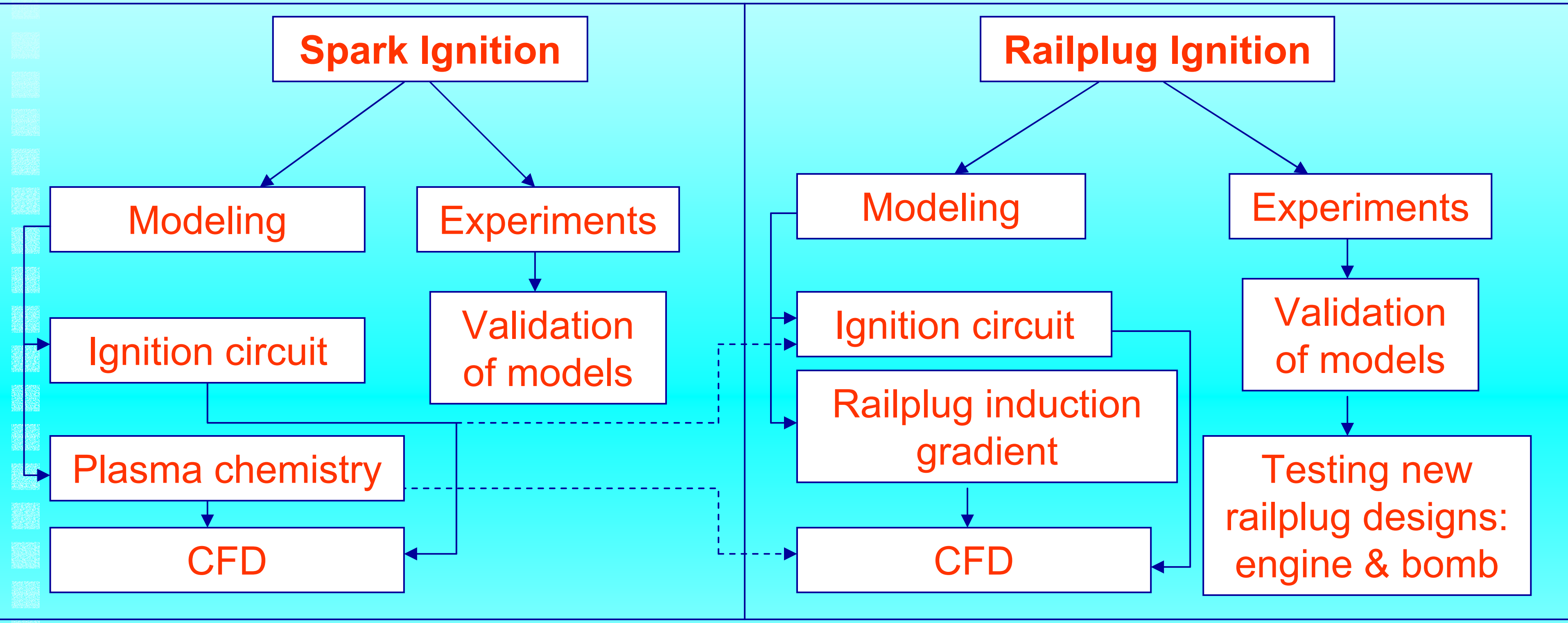
MODELING TASKS

- Circuit models developed
  - For conventional ignition systems
  - For railplug ignition systems
  - 2 papers offered
- Kinetics finalized
- New physics incorporated (breakdown, arc-to-glow transition)
- Running multi-D model

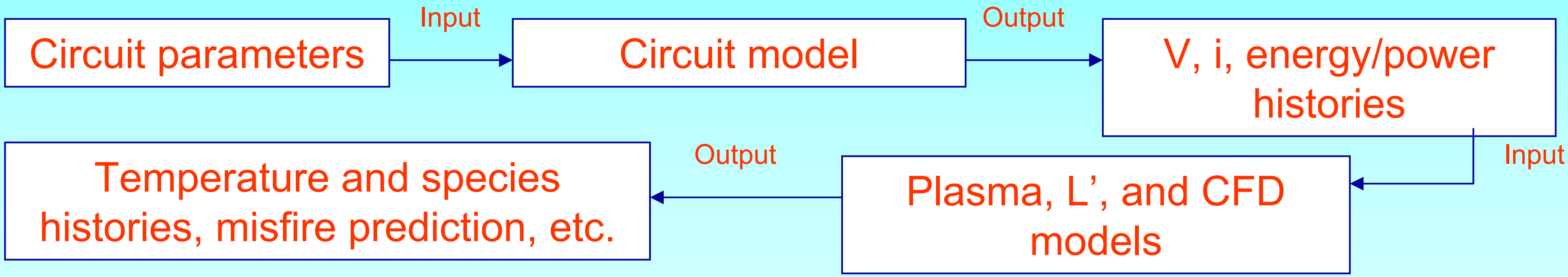
EXPERIMENTAL TASKS

- New railplug designs developed (more to come)
- DoE run for parallel rail designs (more planned)
- Engine test-bed up and running, baselined, starting railplug tests

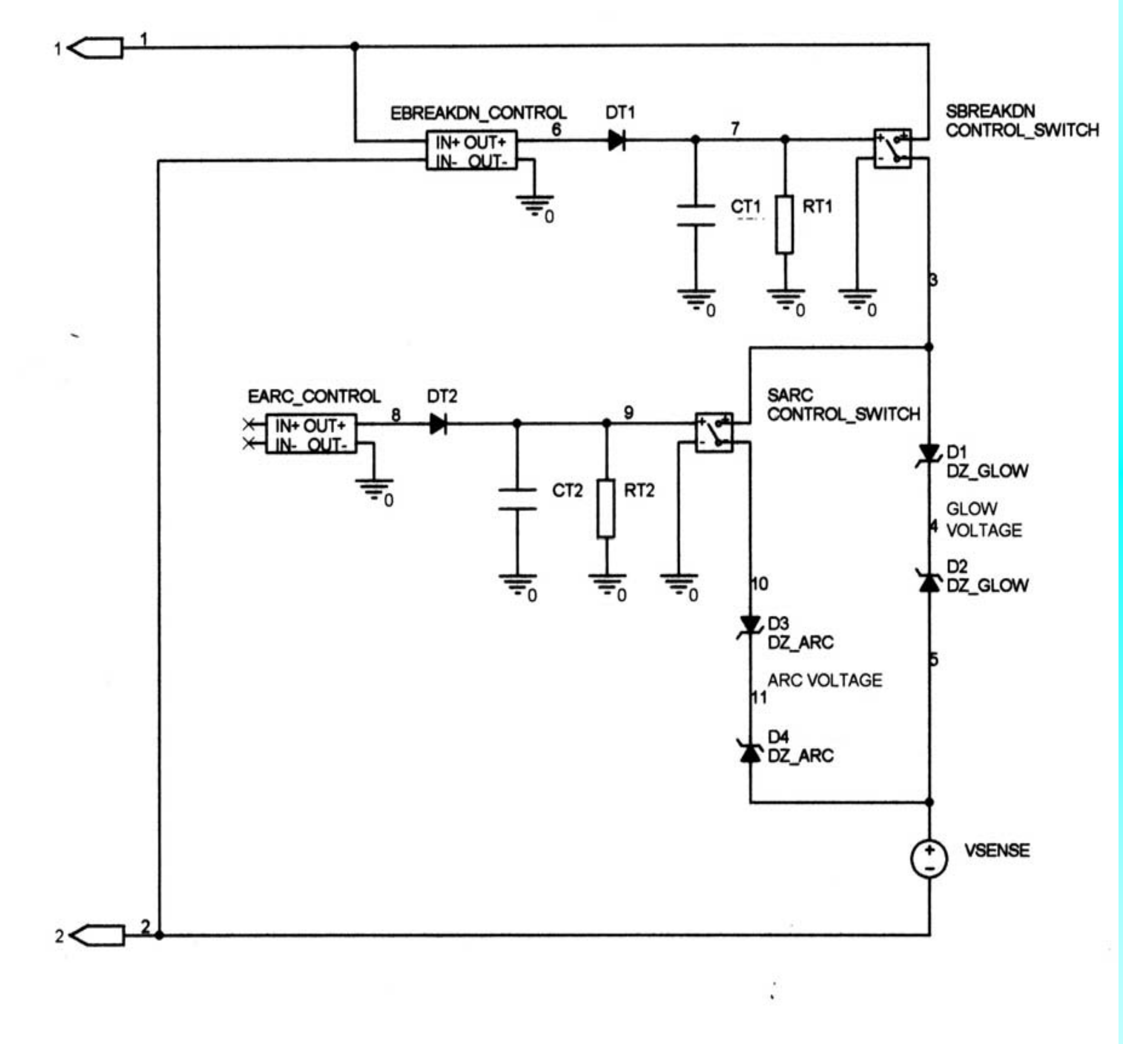
Project Overview



Modeling Process Flow chart



Technical Approach and Results
Circuits



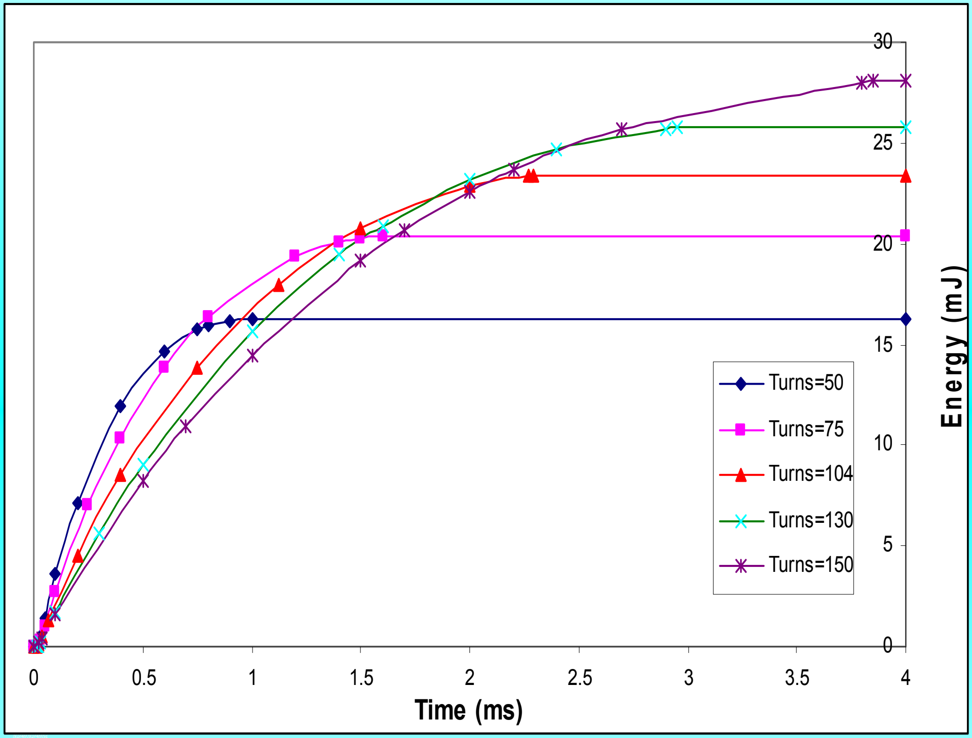
SPARK GAP MODEL

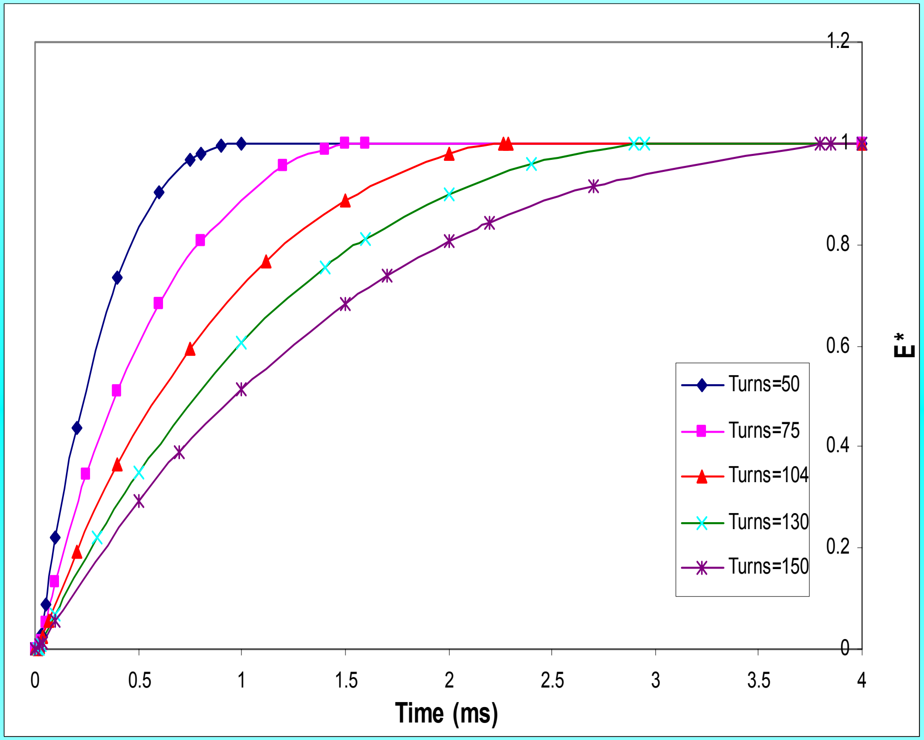
4 phases of spark – response from 4 phases of circuit dynamics:

1. Pre-Breakdown
2. Breakdown
3. Arc
4. Glow

Technical Approach and Results

Circuit MODEL: EXAMPLE RESULTS





Energy deposited

Time for energy deposition

EFFECT OF TURNS RATIO OF THE COIL

Technical Approach and Results

Circuit MODEL: CONCLUSIONS FOR CONVENTIONAL IGNITION SYSTEM

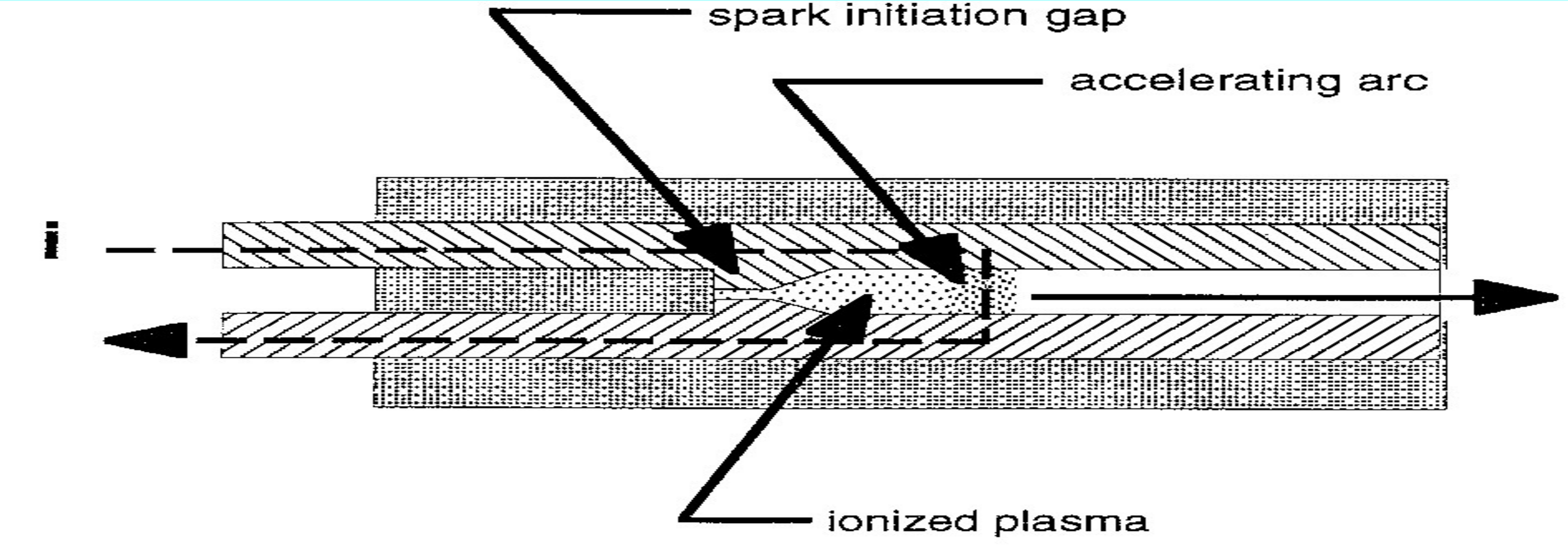
1. **The effects of ignition circuit parameters are**

Increasing parameters	Energy deposited	Time to deposit energy	Extent of Impact
Turns ratio	increases	increases	significant
Primary resistance	decreases	decreases	significant
Core inductance	increases	increases	significant
Secondary resistance	decreases	decreases	weak
Spark plug wire resist.	decreases	decreases	weak

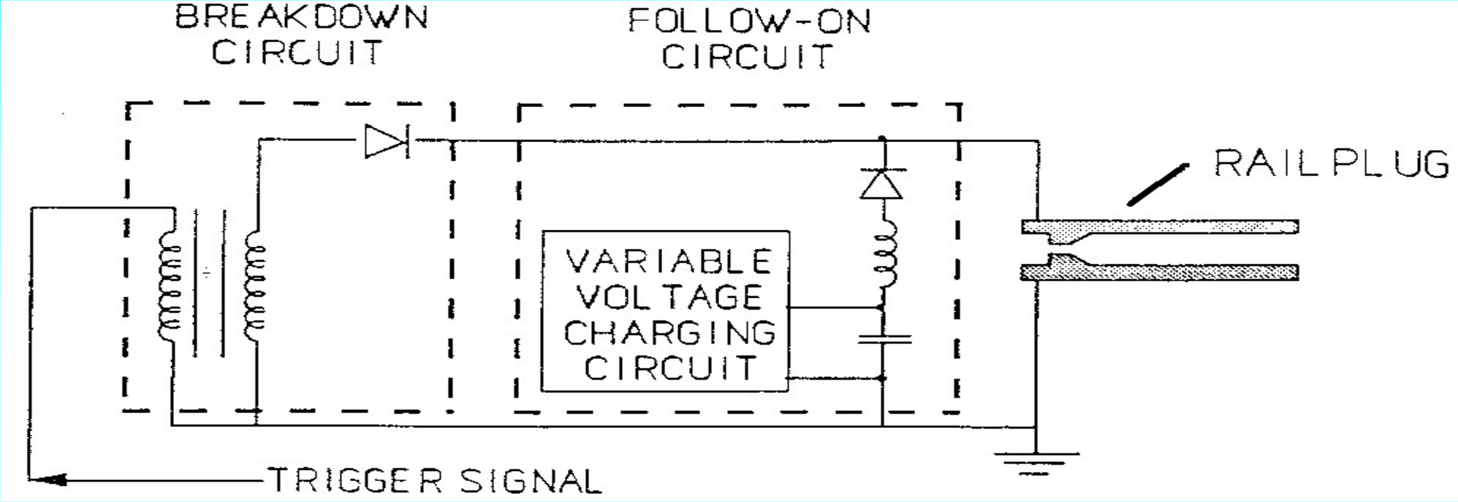
2. **Equation for glow voltage developed and verified experimentally**
3. **Arc-to-glow transition criterion developed**
4. **Model now being used as “driver” for multi-D ignition model: test circuit effects on lean/high BMEP ignition**

Technical Approach and Results

RAILPLUG Circuit MODEL



Lorentz force accelerates arc, spreading energy over large surface area



Technical Approach and Results

RAILPLUG Circuit MODEL: CONCLUSIONS

1. The effects of additional railplug circuit parameters are

Increasing parameters	Energy deposited	Time to deposit energy	Extent of Impact
Follow-on capacitor	increases	increases	significant
Initial Voltage	increases	no effect	significant
Pulse shaping inductance	no effect	increases	significant
Discharging resistance (>50Kohms)	increases	remains same	weak

2. A long duration current pulse is desired to accelerate the arc and move it over a large surface area for minimum erosion.

3. Best to combine high capacitance with low voltage to supply the minimum ignition energy.

Technical Approach and Results

IGNITION MODEL

No ignition models begin in the pre-breakdown phase, or include breakdown. Rather, they begin "after breakdown", but this means the models assume some initial values at some arbitrary time during the arc phase. Somewhat surprisingly, the various models all work reasonably well for conditions for which ignition is "easy". No models have proven capable of providing accurate predictions for conditions when ignition is "challenging". We believe this is due to:

- Inappropriate initial conditions "after breakdown" – we avoid these assumptions by beginning in pre-breakdown
- Failure to include the ignition circuit dynamics (rate of energy deposition) and efficiency – we include this
- Incorrect chemical kinetics – plasma chemistry yields a different path to energy release
- Effects of energy budgeting w.r.t. turbulence, bulk flow, etc. – plan to examine

Technical Approach and Results

IGNITION MODEL

Gas temperatures exceed 6000 K during arc, with increasing T's as ignition energy increases. Flame chemistry is totally inappropriate for these temperatures. Plasma chemistry:

$$CH_4 \rightarrow C + 4H$$

$$O_2 + M = 2O + M$$

$$N_2 + M = 2N + M$$

$$N + e^- = N^+ + 2e^-$$

$$O + H = OH$$

$$C + O = CO$$

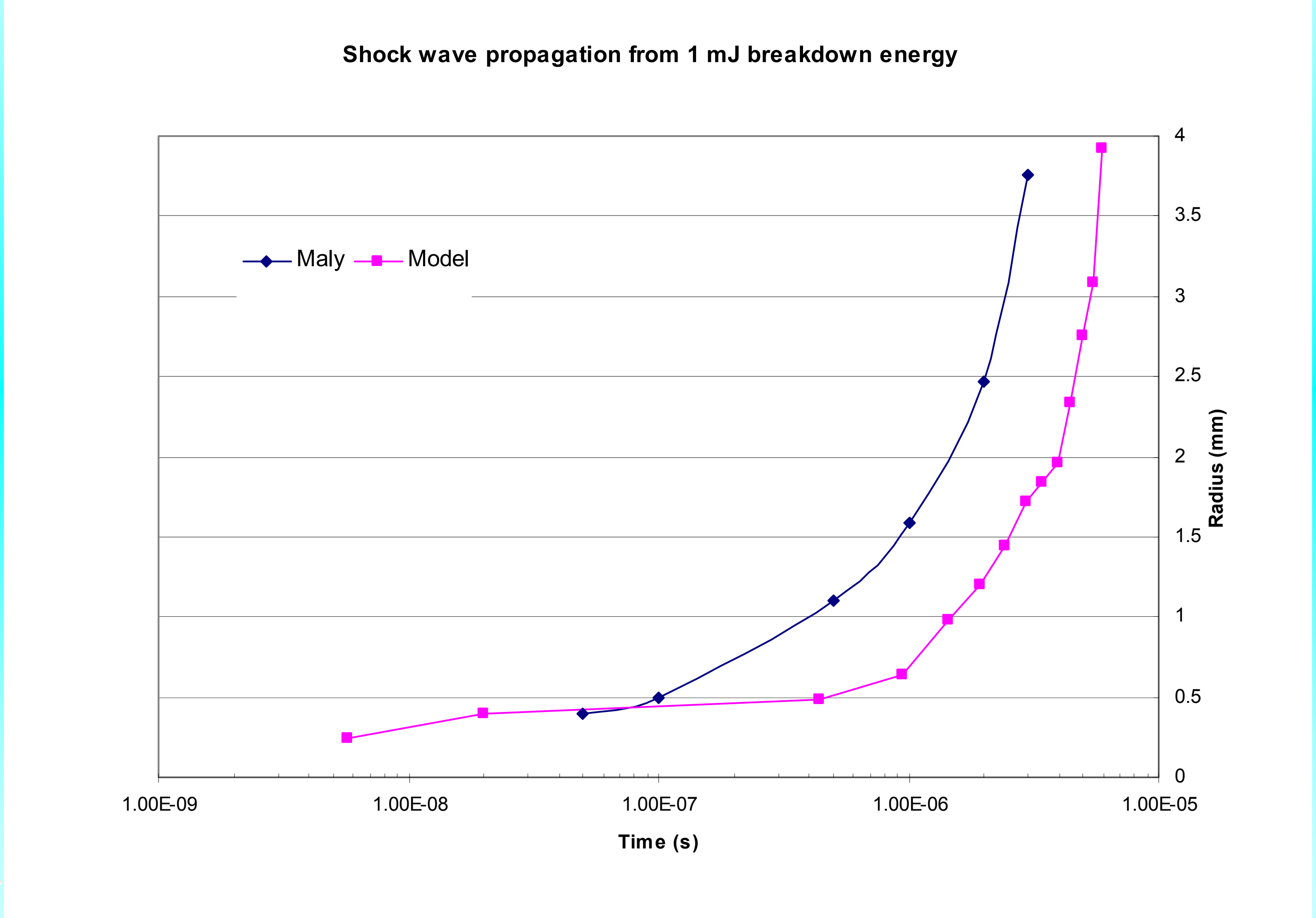
$$CO + OH = CO_2 + H$$

$$H + OH = H_2O$$

We have found the rate expressions for these reactions and the high temperature transport properties

Technical Approach and Results

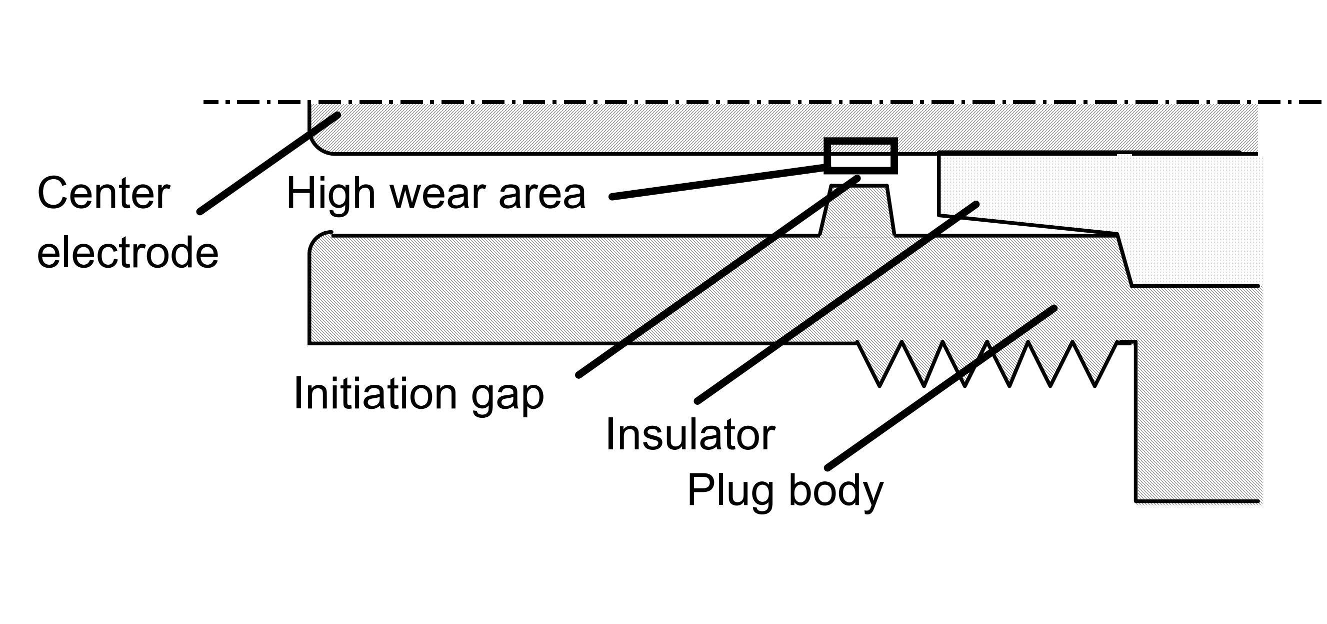
IGNITION MODEL: EARLY Results



Technical Approach and Results

EXPERIMENTS: Railplug Designs

Prior railplug design (Champion 727, coaxial):



$$\Delta V = iR'x + V_{plasma} + iL'u$$

= Joule heating of rails + V drop across plasma + "speed voltage"

L' = inductance gradient (uH/mm) = f(geometry)

Technical Approach and Results

EXPERIMENTS: Railplug Designs

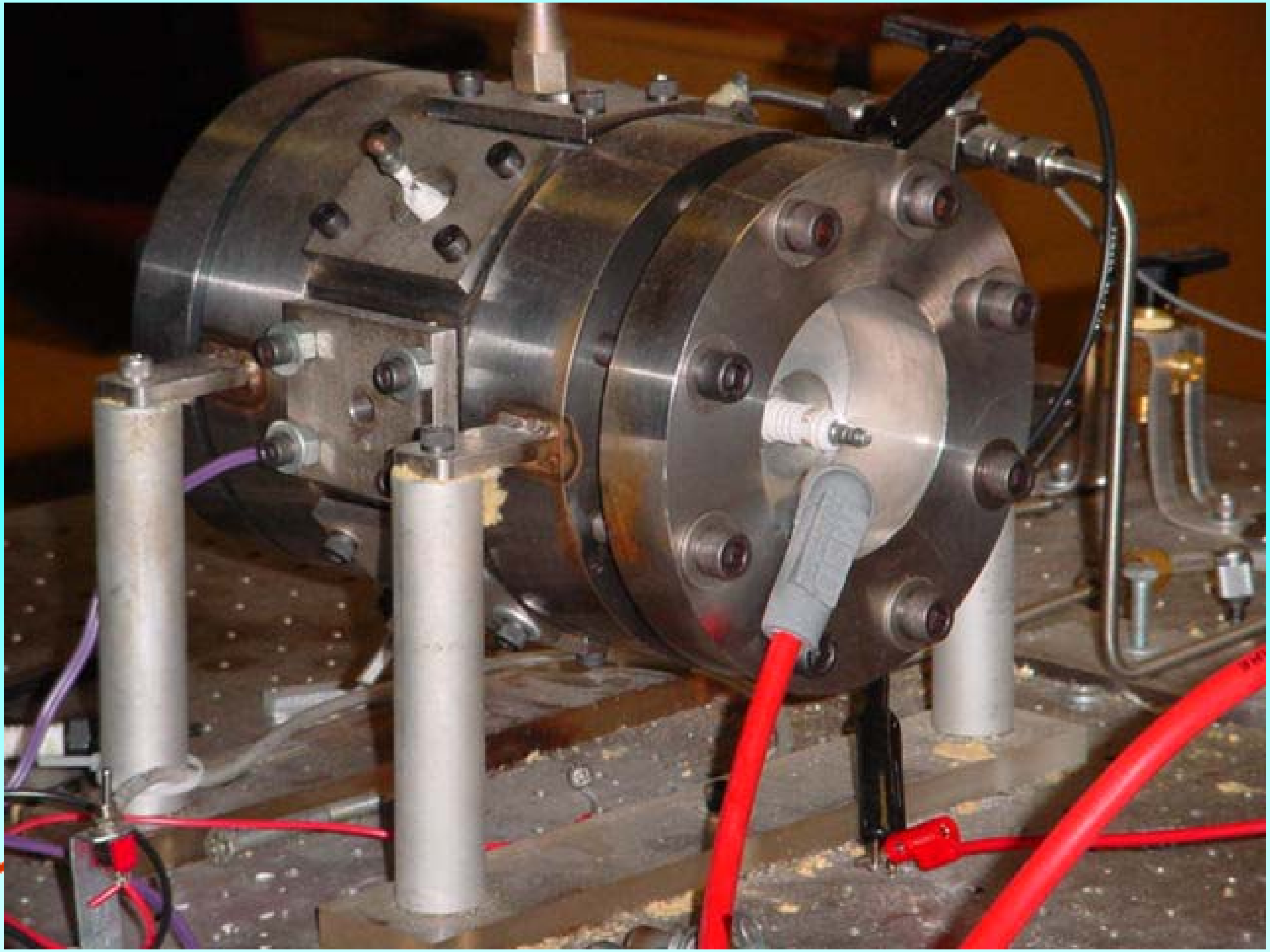
New railplug designs:

- **Parallel rails (higher L')**
- **Tapered outer coax, to eliminate discontinuity**
- **Larger central electrode (coax), tapering down nearer to exit**

Parallel and coax railplugs

Technical Approach and Results

EXPERIMENTS: DoE TESTs



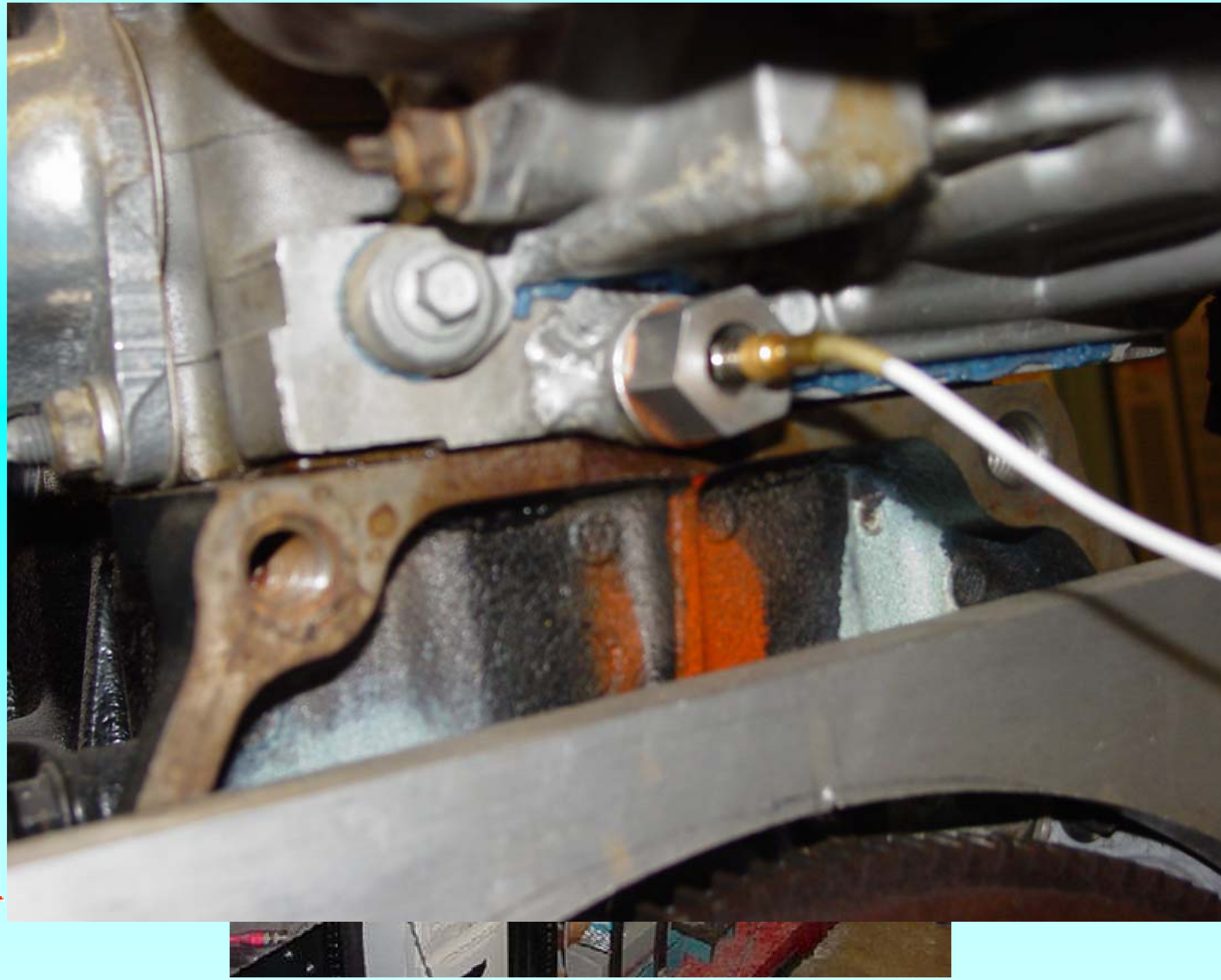
Technical Approach and Results

EXPERIMENTS: DoE Results - parallel

- **Parallel configuration railplug tested to assess how durability is effected by:**
- **Initiation gap size (0.5 – 1.5 mm)**
- **Follow-on Voltage (100 – 150 V)**
- **Storage Capacitance (22 – 100 μf)**
- **Rail Length (2 – 10 mm)**
- **25 different railplugs were tested**
- **Trends were inconclusive due to manufacturing variations among the railplugs - we have refined our railplug manufacturing techniques and expect more conclusive results to follow.**

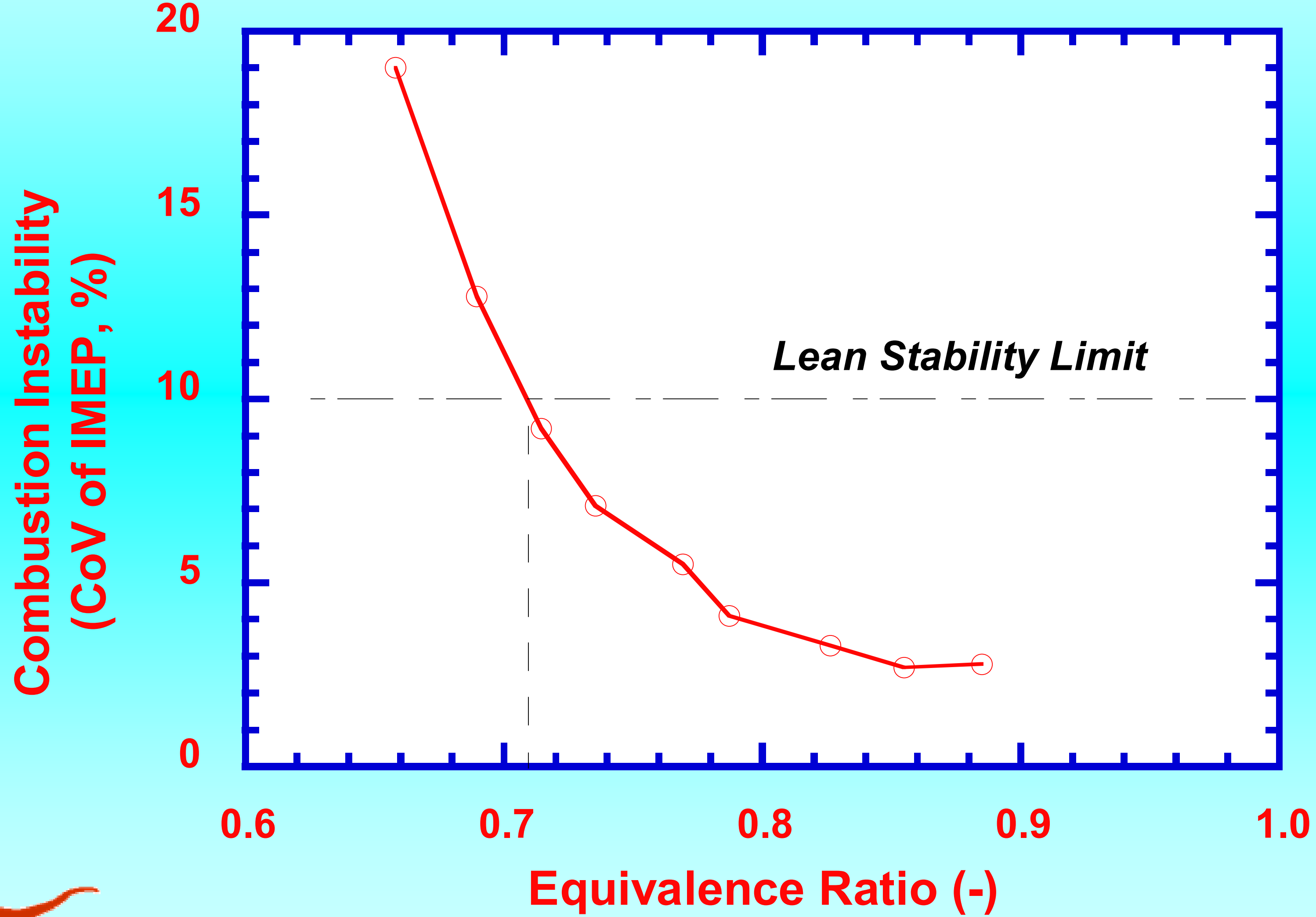
Technical Approach and Results

EXPERIMENTS: engine tests



Technical Approach and Results

EXPERIMENTS: engine tests



Baseline, conventional ignition, CNG, 900 rpm, WOT, MBT

Project Team

Back, L-R: Sreepatti Hari (MS), Prof. DK Ezekoye, Prof. Matt Hall, Pat Seers (PhD)
Front, L-R: Sameer Bhat (MS), Ozgur Ekici (PhD), Hongxun Gao (PhD), Prof. Ron Matthews

UT Engines Research Program Capabilities

- Multi-D modeling
- Quasi-D engine modeling
- Chemical kinetics
- Spark shaping hardware
- Optical engine, combustion bomb
- Laser diagnostics, real-time AF in spark gap, real-time HCs (Fast-Spec), real-time CO2/EGR, real-time PM
- High speed engine data acquisition systems (3)
- 9 engine dynos, 10-1200 hp
- Chassis dyno
- Horiba emissions bench, Rosemount emissions bench, 3 GCs, FTIR

Summary

Objectives:

- Improved model for conventional spark ignition process
- Extension to railplug ignition
- Develop and demonstrate railplug ignition system suitable for LBNGEs

Accomplishments thus far:

- Circuit model for conventional ignition system completed and validated, paper submitted
- Circuit model for railplug ignition system completed and validated, paper submitted
- New multi-D model for spark ignition completed, including new technique (beginning at pre-breakdown), new chemistry, and ignition circuit. In process of validating.
- New railplug designs generated. In process of testing (bomb and engine)
- Engine set-up, baselined

Questions???